

Device Performance and Transport Properties of High Gain Metamorphic InP/InGaAs Heterojunction Bipolar Transistors at Elevated Temperature

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Metamorphic technology - growing the InP-based devices metamorphically on GaAs substrate, has received increasing attention due to its ability to eliminate InP substrate-related issues such as limited substrate size, high cost and brittle nature of the InP substrate. Good performance metamorphic InP/InGaAs heterojunction bipolar transistors (MM-HBTs) grown on GaAs substrate have been demonstrated recently [1,2]. For the InP/InGaAs HBT epi-layer metamorphically grown on GaAs substrate, material quality is one of the most important concern for practical applications. In this study, a detailed dc characterization of metamorphic InP/InGaAs/InP DHBTs in the temperature range of 300 K to 400 K was carried out and the carrier transport properties were investigated. Our experiments reveal that band-to-band recombination is the dominant mechanism for the base current indicating the good base material quality for the metamorphic HBT structures.

The MM-HBTs fabricated in this work were grown by solid-source molecular beam epitaxy (SSMBE) on semi-insulating (100) GaAs substrates. Detailed layer structure and fabrication process have been reported elsewhere [1]. The devices used for characterization have a peak DC gain (β) over 100. Fig.1 plots β versus base doping concentration for both metamorphic and lattice-matched devices using different growth techniques [3-6]. The base thickness of the transistors is about 50 nm. The β of the MM HBT reported in this work is close to those reported for lattice-matched (LM) HBTs with similar base thickness and doping concentration.

A plot of current gain versus collector current at different temperatures is shown in Fig. 2. The decrease of β with the increase in temperature occurs only in the low collector current regime. A typical common emitter I-V characteristics at 400 K is shown in the Fig. 2 as an inset. It can be seen that the device exhibits good output characteristics with low output conductance and leakage current.

To understand the properties of carrier transport in the MM HBTs, and further assess the material quality, temperature dependence of Gummel plots for a $5 \times 10 \mu\text{m}^2$ device is shown in Fig.3. As the temperature increases, the base-emitter turn-on voltage largely decreases, and the crossover of the base and collector currents remains low. No obvious changes of base and collector ideality factors are observed.

To study the carrier transport in the device, collector and base currents in Gummel plots at different temperatures were extrapolated to $V_{BE} = 0$ V to obtain the values of I_{C00} and I_{B00} [7]. Activation energy plots for collector and base current [$\log I_{C00}$ (or $\log I_{B00}$) versus $1/T$] are shown in Fig.4. For the collector current, an E_a of 1.1 eV which is around the sum of InGaAs bandgap ($E_{g \text{ InGaAs}} = 0.75$ eV) and the conduction band discontinuity ($\Delta E_c = 0.22$ eV), indicates the presence of electron injection by thermionic emission. As for the base current, the E_a of 0.8 eV is obtained which is close to the band gap of the InGaAs base, indicating that, in this temperature range, the band-to-band recombination plays a dominant role in determining the base current. No trap-related recombination is observed for the base and the collector currents, which further indicates that the metamorphic HBT structures grown by SSMBE have good material quality.

In conclusion, the temperature dependence of the DC characteristics for a high gain metamorphic InP/InGaAs HBT on GaAs substrate was investigated. The device transport properties for the metamorphic HBTs were studied to access the material quality. The experimental results suggest that, in the temperature range of 300 to 400 K in which the devices are commonly operated, the band-to-band recombination plays a dominant role in determining the base current. No trap-related recombination is observed for the base and the collector currents indicating that the metamorphic HBT structures grown by SSMBE have good material quality and great potential for practical applications.

References:

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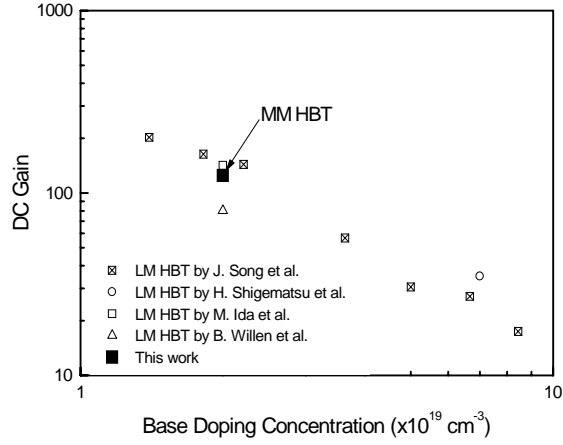


Fig.1 DC current gain versus base doping concentration for metamorphic and lattice-matched devices.

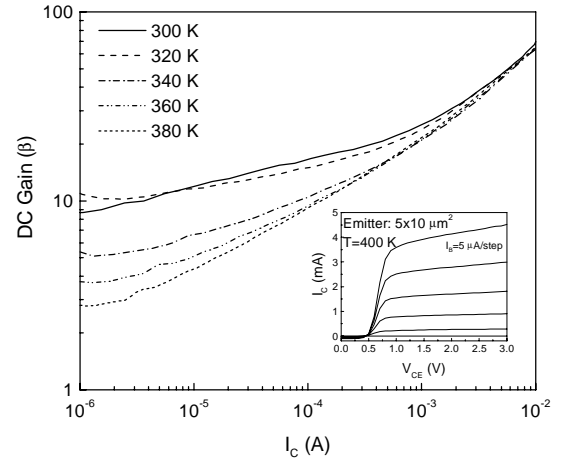


Fig.2 Current gain versus collector current characteristics at different temperatures. Inset: common-emitter I-V characteristics at 400 K.

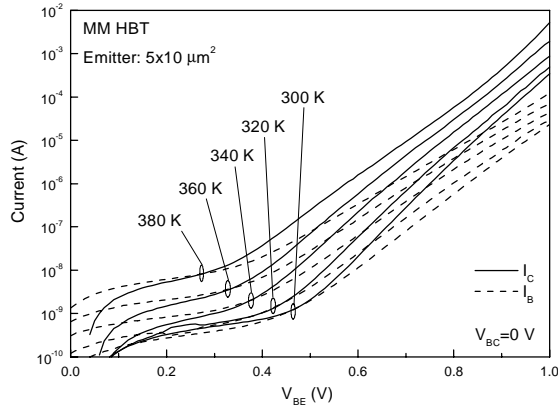


Fig.3 Temperature dependence of Gummel plots for a $5 \times 10 \mu\text{m}^2$ device.

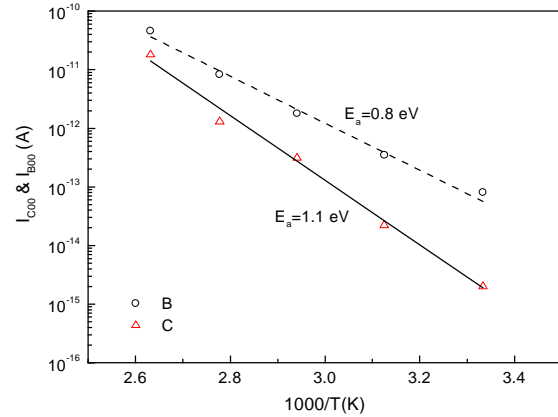


Fig.4 Activation energy plots for collector and base currents extrapolated to $V_{BE} = 0 \text{ V}$ [$\log I_{C00}$ (or $\log I_{B00}$) versus $1/T$].